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(54) **METHOD AND APPARATUS FOR FETAL AUDIO STIMULATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 56 days.

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(65) **Prior Publication Data**

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(51) **Int. Cl.**⁷ **A61B 5/00**

(52) **U.S. Cl.** **600/559; 600/437; 73/585; 381/151**

(58) **Field of Search** 600/437, 443, 600/552, 559, 591, 27, 28; 128/897, 898; 381/301, 312, 326, 332, 333, 385, 388, 151; 73/585

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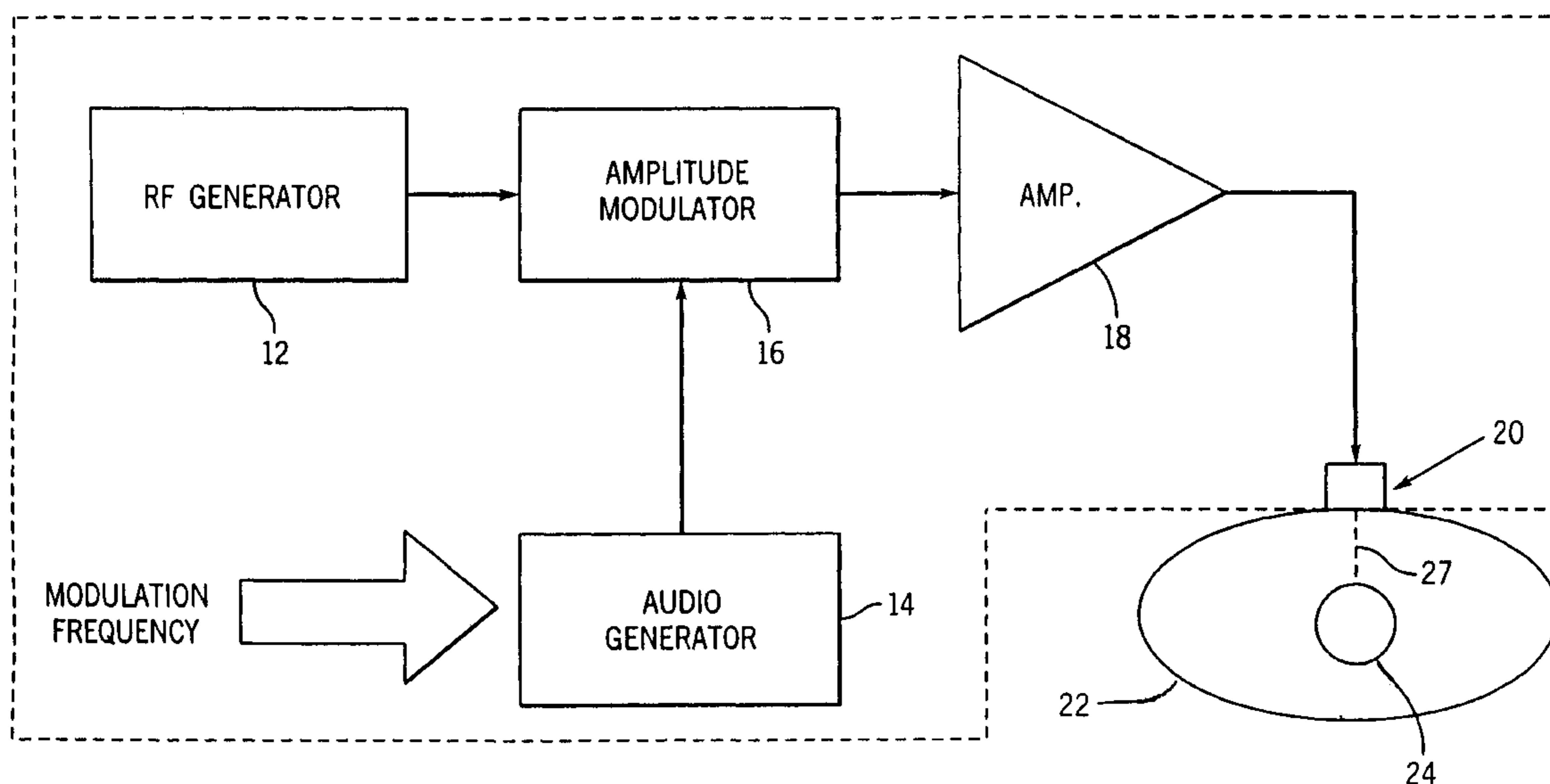
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(57) **ABSTRACT**

The present invention is a method and apparatus for applying a focused, directed audio beam at a fetus to stimulate the fetus in utero. An ultrasound signal is amplitude modulated with an audio range signal, and directed to an ultrasound transducer positioned on the abdomen of a pregnant woman. A focused beam from the ultrasound transducer is directed at the head of a fetus, wherein the resultant audio signal stimulates the middle ear, causing the fetus to move. Motion of the fetus can be tracked to test hearing in individual ears or to test the general health of the fetus. Furthermore, the focused beam can be successively directed at the fetus to cause to the fetus to move to a selected location in the womb for clinical testing or delivery.

21 Claims, 8 Drawing Sheets



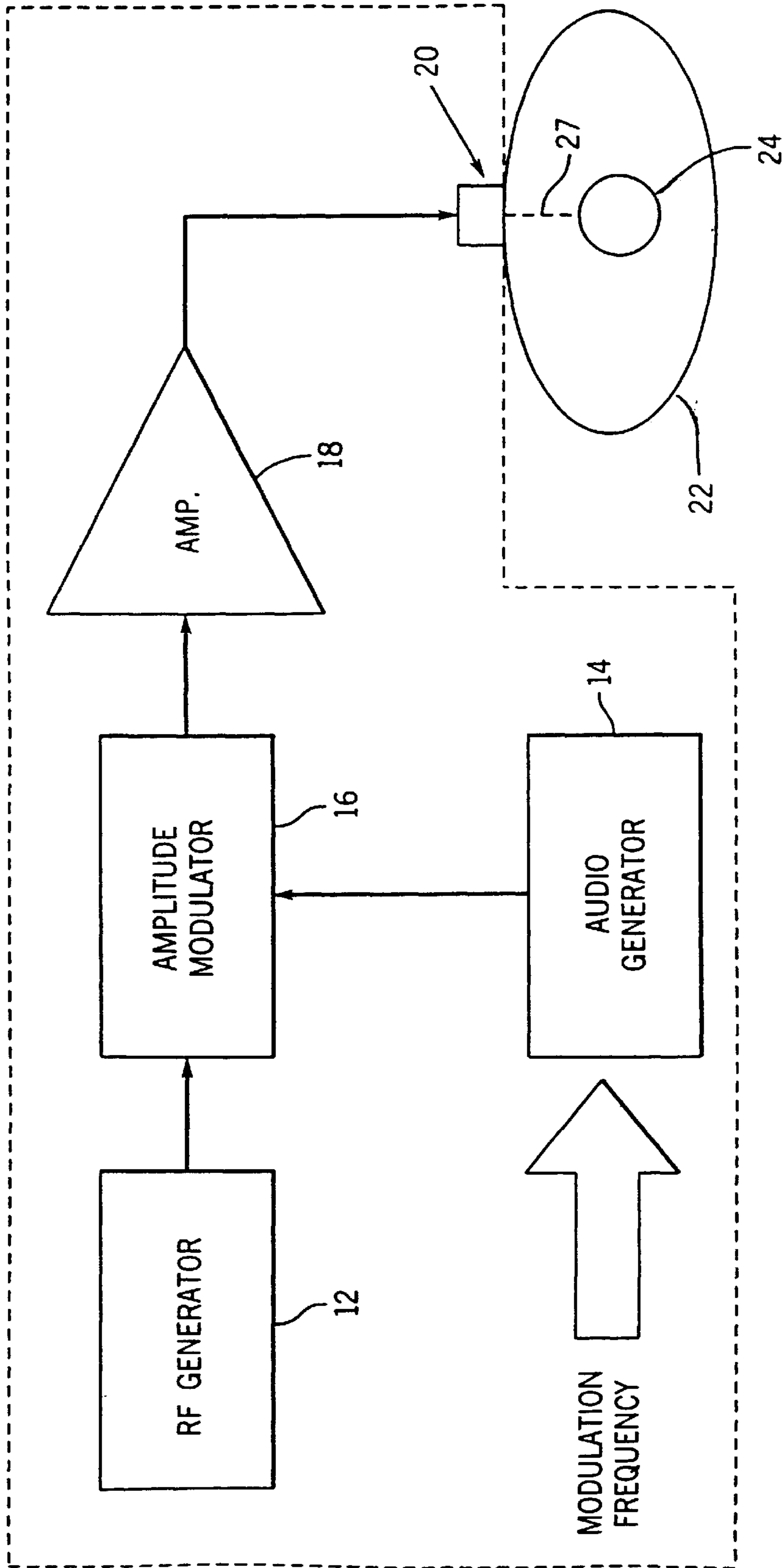


FIG. 1

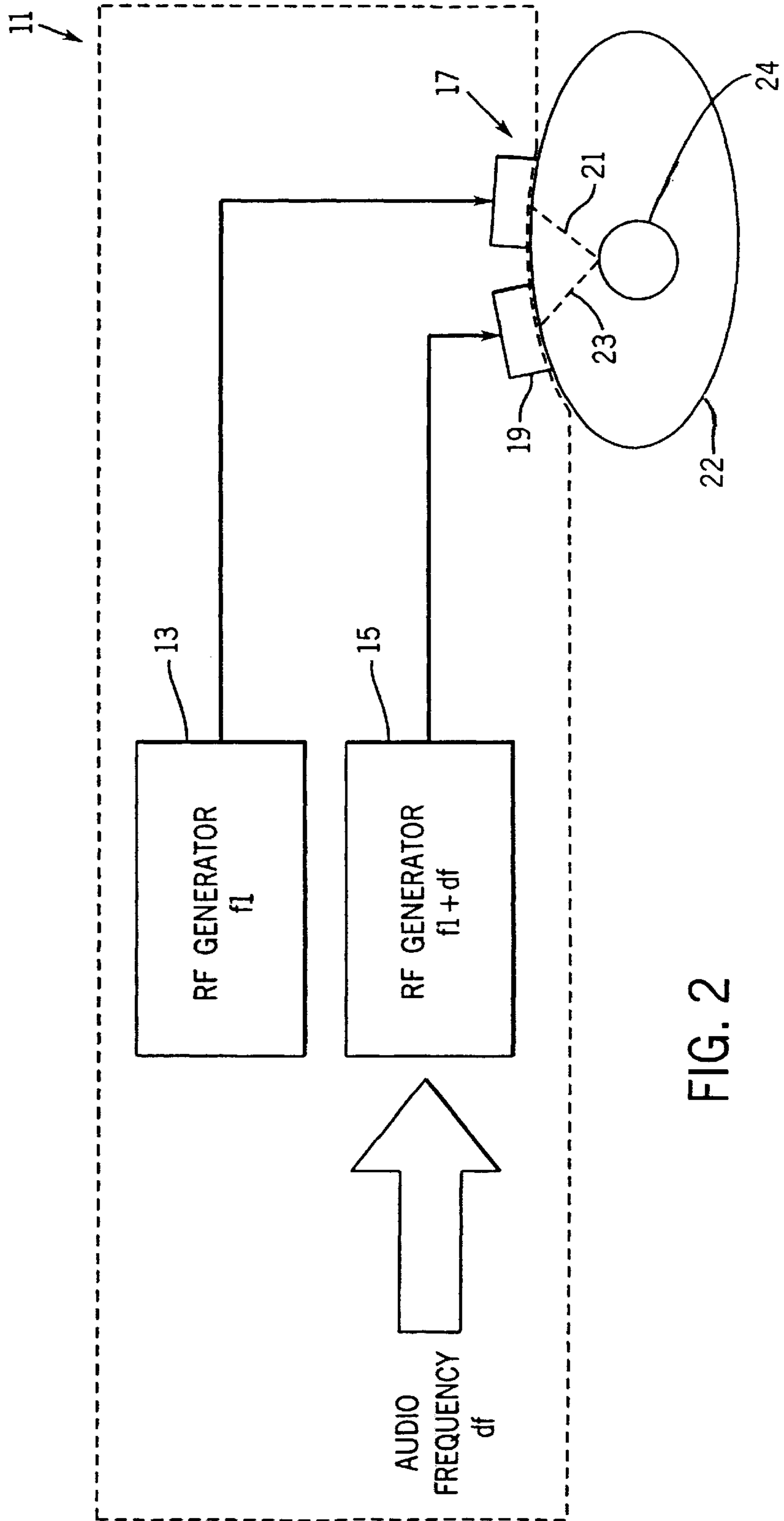


FIG. 2

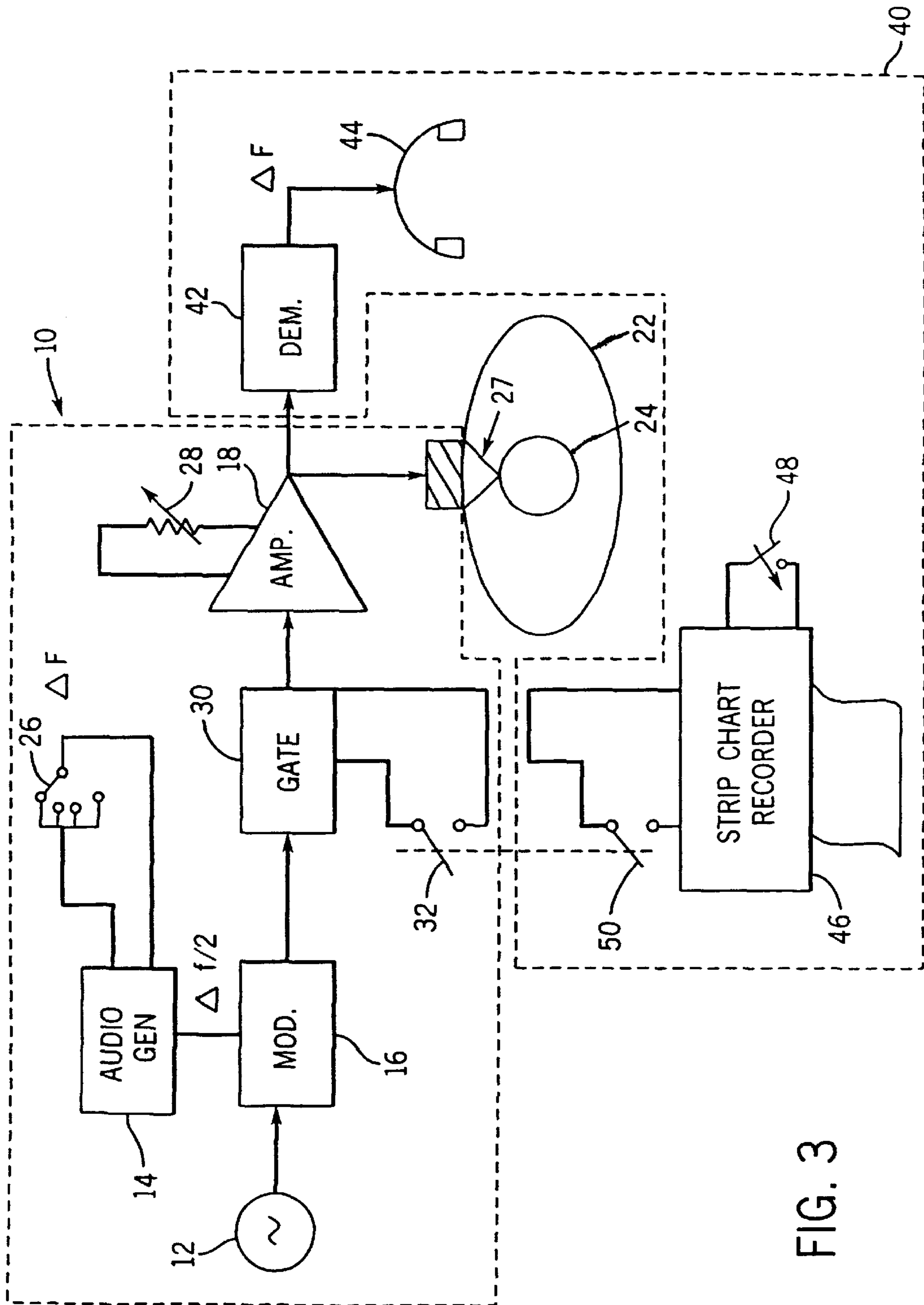


FIG. 3

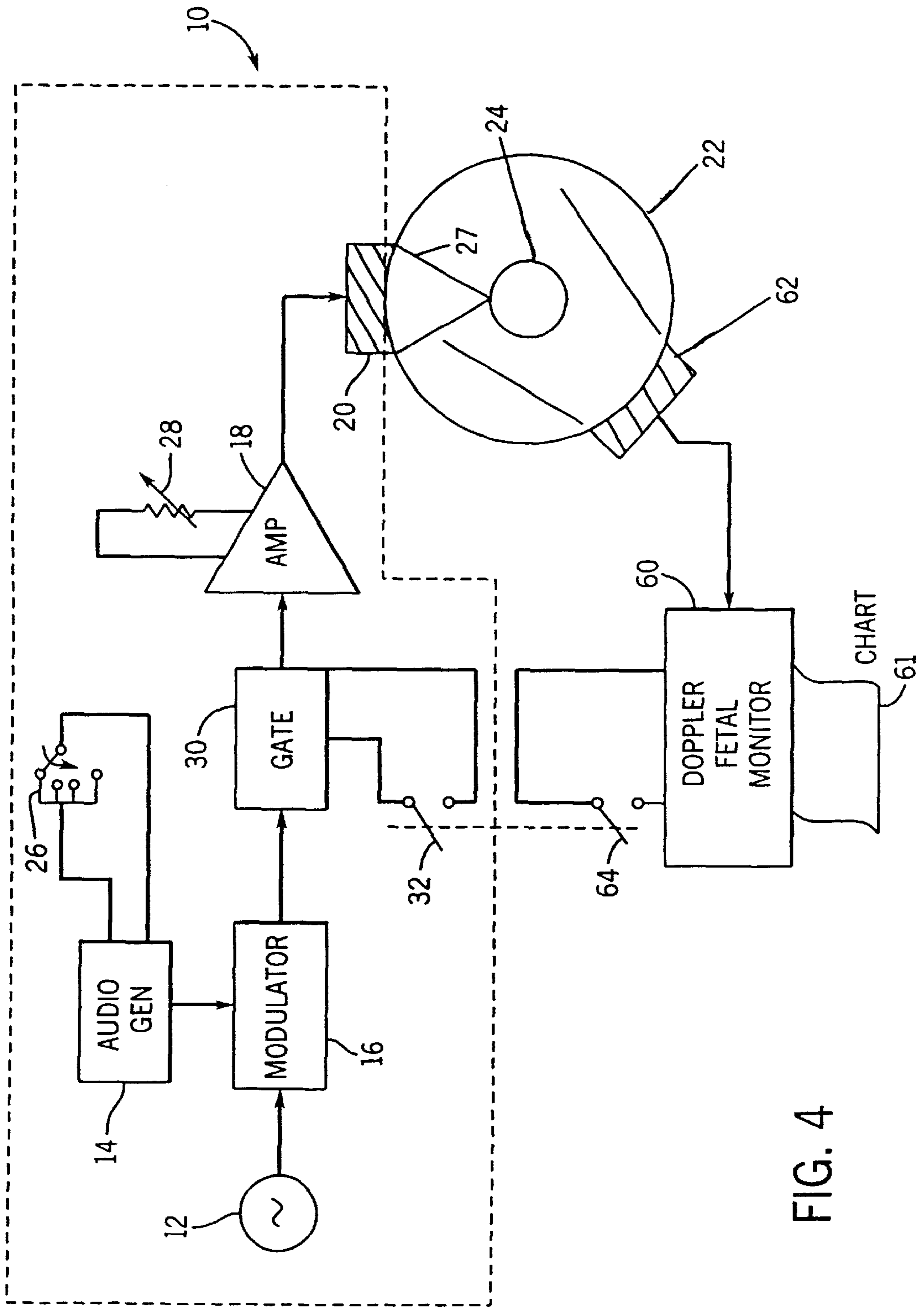


FIG. 4

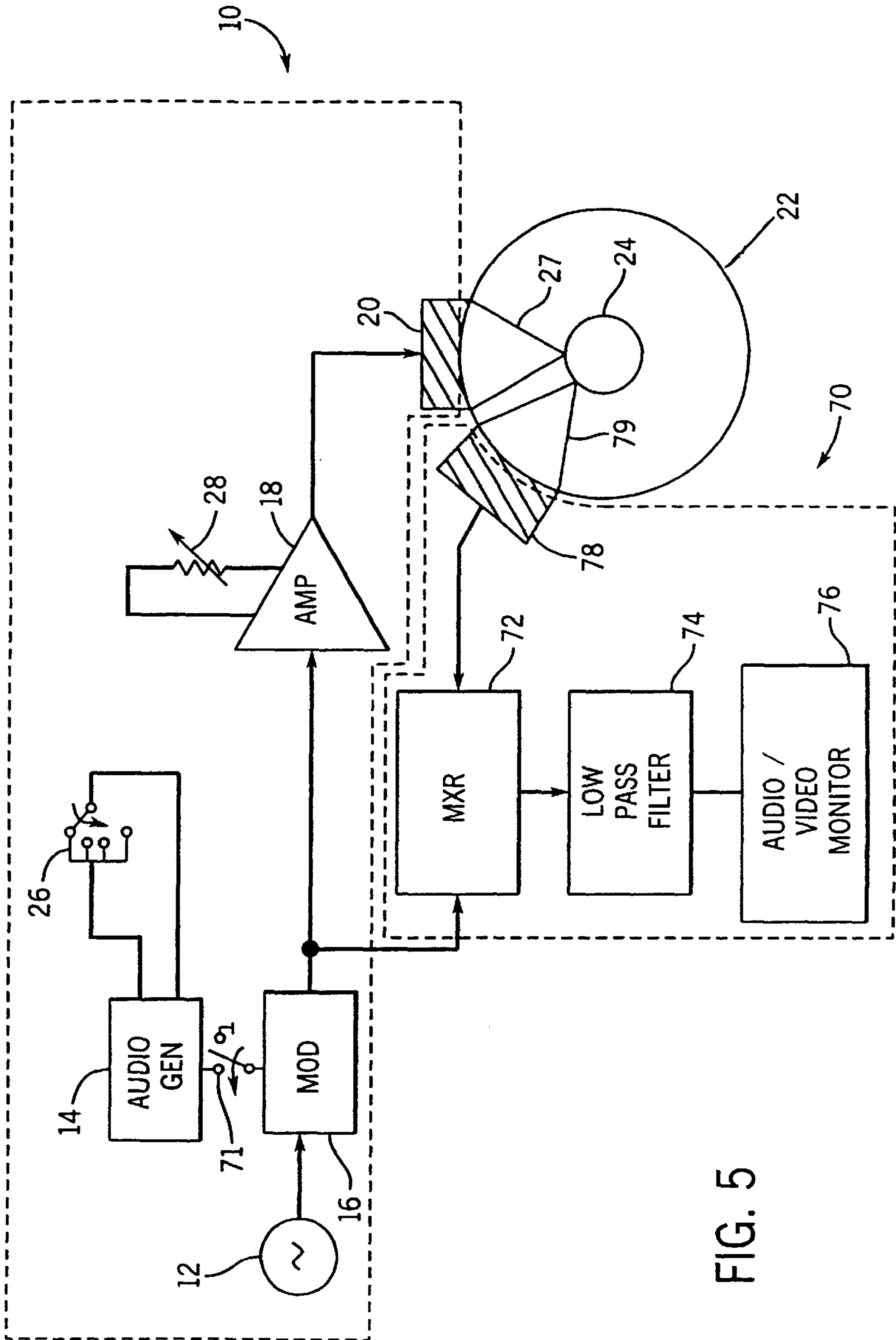


FIG. 5

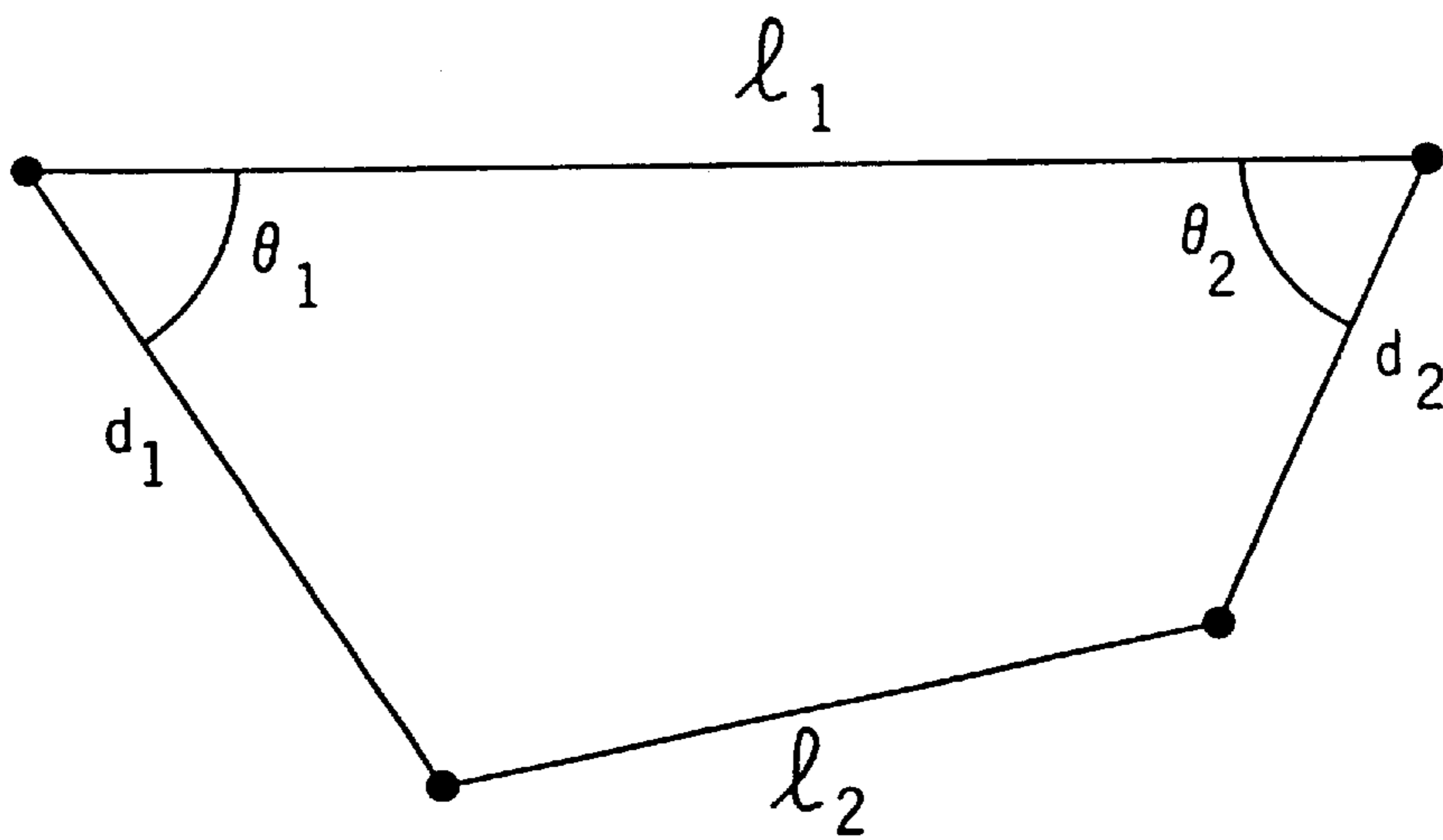


FIG. 7

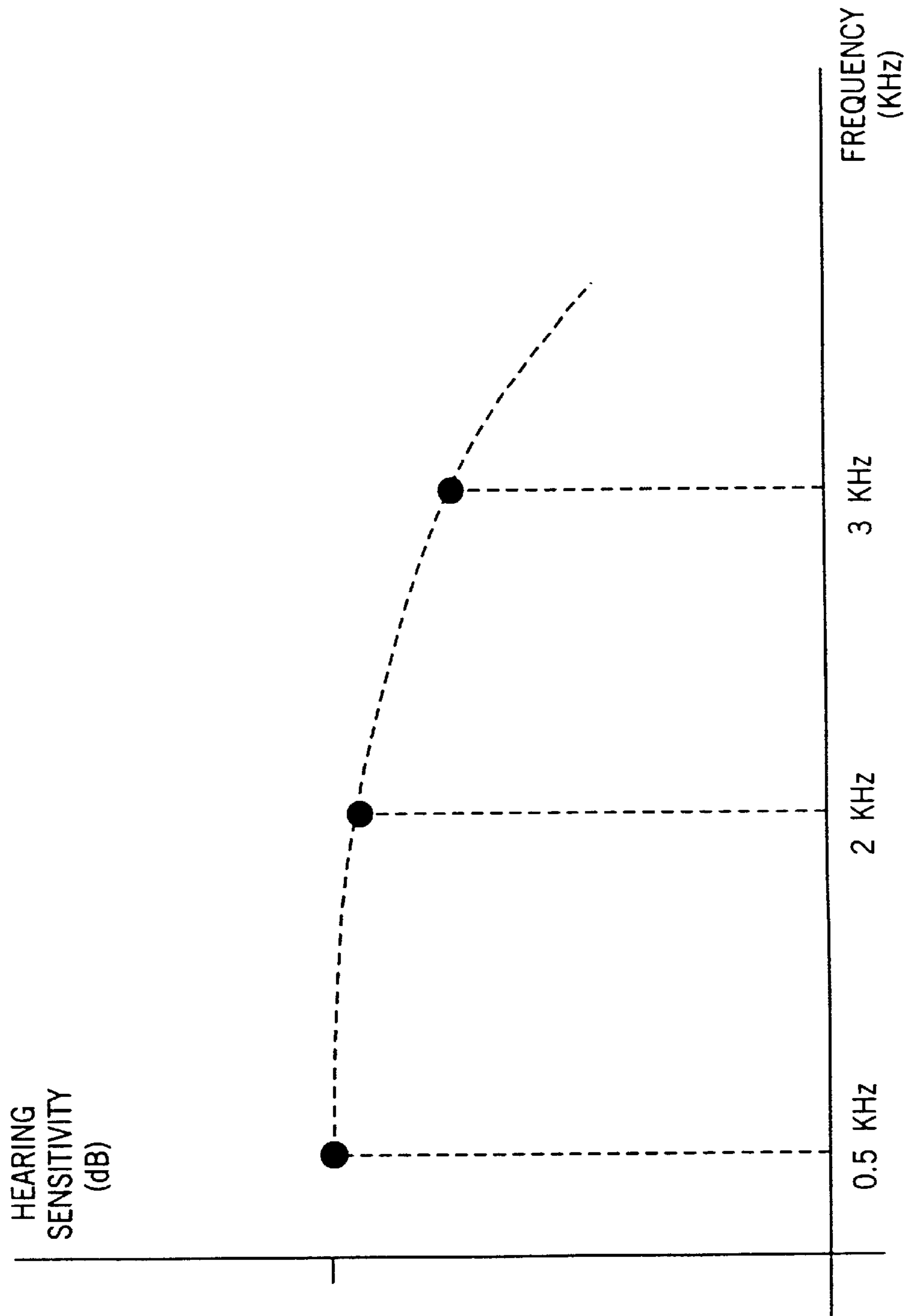


FIG. 8

METHOD AND APPARATUS FOR FETAL AUDIO STIMULATION

TECHNICAL FIELD

The present invention relates to fetal stimulation and testing devices, and more specifically to an ultrasound device for stimulating a fetus in utero and for monitoring movement of the fetus as a result of the stimulation.

BACKGROUND

Audio fetal stimulators are commonly used in clinics to evaluate both the general health and hearing of fetuses in utero. Audio stimulation devices can include both artificial larynxes and devices which employ speakers to "communicate" with the fetus, such as those described in U.S. Pat. Nos. 6,169,814 and 5,913,834. In each of these devices, an audio sound source is generated externally and is transmitted into the abdominal cavity of the mother to stimulate the fetus. Movement of the fetus can be monitored to track reaction to the audio stimulation, and therefore to verify general hearing, assess fetal health based on response to the stimulation, and to analyze other parameters.

While these audio stimulation devices are useful for general testing of both the overall hearing and response of the fetus, there are certain limitations associated with audio stimulation devices of the type described above. These devices, for example, produce sound which is transmitted to the abdominal cavity with little or no directivity. Because the audible sound has very long wavelengths, it tends to spread equally in all directions in the abdomen. Therefore, when audio stimulation is applied to test hearing, the sound is transmitted simultaneously to both fetal ears. It is not possible to test each of the ears individually. Furthermore, although the sound stimulation causes the fetus to move, prior art methods are not designed to cause the fetus to move to a particular position or location in the uterus. Because the sound is almost non-directional, there is no "quiet" place in the uterus at which the fetus would feel less stressed. Hence the fetus moves almost randomly to the audio stimulation.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for audio stimulation of a fetus in utero. The fetal stimulator of the present invention produces fetal auditory stimulation by direct conversion of ultrasound energy to audible sound waves. Hence the fetal stimulator of the present invention can be used to stimulate the fetus in a very specific region.

In the present invention, a focused ultrasound transducer is driven by an amplitude-modulated signal to provide localized, directed energy to the fetus. An RF generator provides a carrier signal at the ultrasound frequency, between 1 and 10 MHz, and an audio modulation generator provides a modulation signal. An amplitude modulator modulates the carrier signal with the audio signal to produce a modulated signal. The resultant modulated signal is used to drive the ultrasound transducer. The transducer, which is positioned on the abdomen of the mother, produces a single focused beam which can be aimed at the fetal head, the ear, or other selected location.

Movement of the fetus can be monitored in a number of known ways, movement can be monitored, by the mother, which provides an indication when she senses fetal movement. Alternatively, fetal movement can be monitored by a Doppler fetal monitor, through analysis of Doppler shift data

from applied and received signals, and by synchronization to a heart beat of the fetus. The fetal stimulator described above can be applied in a number of different clinical applications, and is particularly suited for use in assessment of the hearing and general health of a fetus.

It is an object of the invention to provide a method and apparatus for selectively applying a highly localized, highly directive, and calibrated energy beam to a fetus.

It is another object of the invention to provide a method and apparatus for monitoring motion of a fetus in conjunction with the application of a highly localized, highly directive ultrasound beam.

It is yet another object of the invention to provide a method and apparatus for individually testing the hearing in each of the ears of a fetus in utero.

It is still another object of the invention to provide a method and apparatus for repositioning a fetus in the womb.

It is yet again another object of the invention to provide a method and apparatus for testing the general health of a fetus.

The foregoing and other objects and advantages of the invention will appear from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown by way of illustration a preferred embodiment of the invention. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims herein for interpreting the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a fetal audio stimulator constructed in accordance with one embodiment of the invention;

FIG. 2 is a block diagram of a fetal audio stimulator constructed in accordance with a second embodiment of the invention;

FIG. 3 is a block diagram of a fetal audio stimulator and associated monitoring device constructed in accordance with another embodiment of the invention;

FIG. 4 is a block diagram of a fetal audio stimulator and associated monitoring device constructed in accordance with another embodiment of the invention;

FIG. 5 is a block diagram of a fetal audio stimulator and associated monitoring device constructed in accordance with another embodiment of the invention;

FIG. 6 is a block diagram of a fetal audio stimulator and associated monitoring device constructed in accordance with another embodiment of the invention; and

FIG. 7 is a graph illustrating the calculation of the distance between the heart and ear of a fetus for use in conjunction with the embodiment of FIG. 6.

FIG. 8 is a typical audiogram developed for a single ear of a fetus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

When ultrasound interacts with an object, a small radiation force is exerted on that object as a result of momentum change by such interaction. For an ultrasound beam with the total power of P , this force is given by $F=P/c$, where c is the speed of sound in the medium. For an amplitude modulated ultrasound beam with the amplitude $U(t)=U_0 \text{Cos}(\Delta\omega t^2)\text{Cos}(\omega_0 t)$, the resulting force will be in the form of $F(t)=F_0+F_0$

$\text{Cos}(\Delta\omega t)^4$. This force vibrates the object at frequency $\Delta\omega$. If the frequency ω is selected to be in the audio range, and the beam is directed to the structures in the middle ear, for example, a sound at this frequency is heard. When the beam is directed at a fetus in utero, the beam can be used to stimulate the fetus and cause the fetus to move. Furthermore, the motion of the fetus can be monitored to test hearing and to provide a general health assessment of the fetus.

Referring now to the figures and more particularly to FIG. 1, a first embodiment of an ultrasound signal generator or fetal audio stimulator **10** for generating an ultrasound beam as described above is shown. The fetal audio stimulator **10** comprises an RF generator **12**, audio generator **14**, amplitude modulator **16**, amplifier **18** and ultrasound transducer **20**. The RF generator **12** provides a carrier signal in the ultrasound frequency between 1 and 10 Mhz and the audio generator **14** provides a modulation signal whose frequency is in the audio range. The carrier signal from the RF generator **12** and the audio signal from the audio generator **14** are each directed to the amplitude modulator **16**, which amplitude modulates the carrier signal with the audio signal, preferably by using a double side band suppressed carrier method to produce a modulated output signal. The modulated output signal is in turn directed to the amplifier **18**, which amplifies the signal to a predetermined level. The amplified signal is then directed to the ultrasound transducer **20** which produces a single focused output beam **27**. In use the ultrasound transducer **20** is positioned on or coupled to an abdomen **22** of a mother carrying a fetus, and the beam **27** is directed at the head **24** of the fetus, and preferably at the ear of the fetus. The beam **27** produces a force which vibrates the head of the fetus **24** or a portion thereof at the audio frequency established by the audio generator **14**.

Referring now to FIG. 2 an audio ultrasound signal generator or fetal audio stimulator **11** constructed in accordance with a second embodiment of the invention is shown. The fetal audio stimulator **11** comprises a first RF generator **13** providing a continuous wave signal at a first frequency f_1 and a second RF generator **15** providing a continuous wave signal at a frequency f_1 plus df , where df is an audio frequency that can be adjusted by the user. The RF generator **13** drives a first ultrasound transducer **17** while the RF generator **15** drives a second ultrasound transducer **19**. Each of the ultrasound transducers **17** and **19** are positioned on or coupled to an abdomen **22** of a mother carrying a fetus. Each of the ultrasound transducers **17** and **19** produce a focused beam **21** and **23**, respectively, which is directed at the head **24** of the fetus. In this application the stimulation site is located at about the intersection of the focal points of the two focused beams **21** and **23**, where a "beat" force is generated at a frequency df . The generation of this force is described more fully in U.S. Pat. No. 5,991,239 which is hereby incorporated by reference. The use of the intersection of two beams **21** and **23** allows the stimulation to be aimed at a specific location with a higher degree of precision than the use of the single beam, described above. Furthermore, this method confines the resultant beam force mainly to the intersection region.

Referring now to FIGS. 3-6, four embodiments of clinical testing devices comprising a signal generator or fetal audio stimulator **10** and associated monitoring device are shown. Each of these devices comprise a fetal audio stimulator **10**, and a monitor device comprising a motion detector and/or an event tracker. These devices can be used for stimulating a fetus and tracking resultant responses, and are useful in clinical situations as described below.

Referring now specifically to FIG. 3, a fetal audio stimulator **10** is shown in use in conjunction with an event tracker

or monitoring device **40**. The fetal audio stimulator **10** of FIG. 3 is constructed as described with reference to FIG. 1 above. The fetal audio stimulator **10** of FIG. 3, however, further includes a frequency selector **26** allowing a physician or other user to select between a number of audio frequencies. The frequency selector **26** is graduated in terms of different values of Δf . An amplitude control **28** shown as comprising a potentiometer in a feedback loop of the amplifier **18**, allows a user to select an amplification level for the amplitude modulated signal directed to the ultrasound transducer **20**. The fetal audio stimulator **10** further comprises a gate **30** selectively activated by gate control switch **32** allowing a physician or other user to selectively apply the amplitude modulated signal to the amplifier **18**, thereby controlling the duration of the application of the beam **27** to the head **24** of the fetus.

The event tracker or monitoring device **40** is a mother-controlled monitor. The monitoring device **40** comprises an envelope detecting demodulation circuit **42** for demodulating the amplitude modulated signal provided to the ultrasound transducer **20**, thereby recovering the audio sound generated by the radiation force of ultrasound, i.e., the selected frequency Δf . The demodulated signal is provided to an earphone **44** which can be worn by the mother to detect when a beam **27** has been applied to the head **24** of the fetus. A strip chart recorder **46** records an event when a mother or other user detects motion of the fetus and activates a first marker switch **48**, and also by the marker switch **50** when the gate-controlled switch **32** is activated by the physician to apply the amplitude modulated signal to the ultrasound transducer **20**. Therefore, the chart records each application of sound to the fetus (marker switch **50**) and any subsequent fetal movements as recorded by the mother (marker switch **48**).

Referring now to FIG. 4 a second embodiment of a monitoring device is shown. In this embodiment the event tracker or monitoring device comprises a low power ultrasound Doppler fetal monitor **60** coupled to a fetal monitor probe **62** which is positioned on or coupled to the abdomen **22** of the mother. In this application, the ultrasound frequency of the probe **62** can be different from that of the ultrasound transducer **20**, and the beam of the monitor probe **62** is preferably less focused than that of the ultrasound transducer **20**, so it can detect fetal motion within a wide field of view. The Doppler monitor **60** further includes an event recorder **61** which records both fetal motion and each application of ultrasound introduced to the fetal ear, as indicated. Events can be recorded on a paper chart or stored in a digital memory associated with the event recorder **61**. The user can therefore evaluate fetal motion resulting from each stimulation applied to the fetal head or ear. The Doppler monitor **60** can be selectively activated by a switch **64**.

Referring now to FIG. 5 a third embodiment of a fetal audio stimulator **10** and associated event tracker or monitoring device **70** are shown. In this embodiment, the ultrasound source that is used for stimulating the fetus is also used for fetal motion detection, thereby allowing for direct detection of motion of the body region exposed to stimulation. Here again the fetal audio stimulator **10** is constructed basically as described with respect to FIG. 1. In this embodiment, however, a physician controlled switch **71** is positioned between the amplitude modulator **16** and the audio generator **14** thereby allowing a physician or other user to selectively apply an audio signal to the amplitude modulator **16**, allowing the physician to produce audio sound in the fetal hearing system whenever he wishes and for any duration.

The monitoring device **70** comprises a downmixer **72** and associated receiving transducer **78**, which receives reflected ultrasound signals **79** from the fetal head **24**. The ultrasound transducer **20** and receiving transducer **78** are located in proximity to each other and are each directed at the same region of the head **24** of the fetus. Furthermore, the center frequency receiving transducer **78** is selected to be substantially the same as that of the ultrasound transducer **70**. The mixer circuit **72** receives an amplitude modulated signal from the amplitude modulator **16**, and a reflected signal from the receiving transducer **78**, and downmixes these two signals. The output of the mixer circuit **72** is coupled to a low pass filter **74** which receives and filters the down-mixed signal to detect a Doppler shift in the frequency of the reflected ultrasound field indicative of whether fetal motion has occurred. From the low pass filter this signal is passed to an audio-video monitor **76** which produces a signal indicative of the Doppler shift described above. This unit can display the Doppler shift by a video (CRT) monitor, or can use an audio device such as a speaker. In this application, the monitoring device **70** can detect motion when the switch **71** is in the On or Off position. However, because the Doppler shift is different when the switch **71** is at On or Off position, the resultant signals can be differentiated.

Referring now to FIG. **6** a fourth embodiment of a fetal audio stimulator **10** and associated monitoring device **80** is shown. In this application the transducer **20** is coupled to a first end of an arm **81** and the receiving transducer **86** is coupled to a second end of the arm **81**. Each of the ultrasound transducer **20** and receiving transducer **86** are pivotally coupled to the arm **81** via pivoting members **82** and **84** which allow the transducers to be directed at a specific portion of the fetus. The receiving transducer **86** is coupled to a Doppler fetal monitor **88** and associated earphone **90** which is used to locate the heart **83** of the fetus while the transducer **20** is directed at the head of the fetus as described above.

In the embodiment of FIG. **6**, the Doppler fetal monitor **88** produces a narrow beam, low-power, Doppler ultrasound beam that is used to detect fetal heart motion. This system is designed to locate the position of fetal heart with high accuracy, and in contrast to conventional Doppler fetal heart monitors, the ultrasound beam of this system is narrow and is focused on the fetal heart. The ultrasound power of the heart locator is set below the fetal stimulation level, hence it has no effect on the fetus.

The length of the arm **81** is approximately equal to the typical distance from the fetal heart to its head. To operate this device, the physician first searches for the fetal heart **83** by aiming the receiving transducer **86** at the fetus and receiving a response from the fetal monitor **88**, for example through a set of earphones **90**. Once the fetal heart has been identified by the fetal monitor **88**, the physician orients the arm **81** in the direction of fetal head. Then, the ultrasound transducer **20** is oriented at an angle selected such that the distance between the focal points of the receiving transducer **86** and ultrasound transducer **20** is approximately equal to the heart-to-ear distance of an average fetus, at the age of the fetus being tested. Referring now to FIG. **7** given the length of the arm **81** (l_1) the focal length of the receiving transducer **86** (d_1), and the focal length of the ultrasound transducer **20** (d_2), the distance between the fetal heart and fetal head (l_2) can be calculated using simple geometry, thereby allowing a physician or other user to calculate and track the position of the fetal ear for purposes of applying a hearing or other test. Once the transducers are adjusted for the fetus, there-

fore fetal movement is tracked by the fetal heart monitor, and consequently the position of fetal ear can be tracked.

Each of the fetal audio stimulators **10** and **11** and associated monitoring devices described above can be used for stimulating and monitoring a fetus in clinical applications. In particular, the present invention can be used as a positioning device for positioning the fetus in the womb, or as an analysis device for assessing general health or hearing of the fetus.

One application for the fetal audio stimulators **10** and **11** is in fetal positioning. In this application, the localized source of fetal auditory stimulation is directed at the head **24** of the fetus to produce a stress to the fetus. The stressed fetus tries to avoid the stimulation by moving its head out of the stressful region, and hence assumes a new position. By moving the ultrasound transducer **20** or successively directing the ultrasound transducer **20** at selected locations on the fetus, a physician or other user can guide the fetus to a desired location in the uterus. Because fetal position before and during labor is critical, one clinical application of this device is to drive the fetus to the proper position in the uterus before labor. Another application is to use the fetal stimulation device **10** or **11** to position the fetus in a selected position before performing a diagnostic procedure on the fetus. For example, physicians can use the fetal audio stimulator **10** or **11** to move the fetus to a proper position before sonography or a maternal examination. Motion of the fetus can be monitored using any of the techniques described above, through imaging techniques, or in other ways known to those of skill in the art.

A second application of the fetal audio stimulators **10** and **11** is in assessing fetal health. The fetal audio stimulators **10** and **11** described above may be used to assess fetal health by stimulating the fetus and evaluating its response to the stimulation. Fetal response again may be detected and recorded in a number of ways, including any of the methods described above and through ultrasound imaging device. The fetal audio stimulators **10** and **11** presented here may also be integrated as a part of a fetal assessment test, such as the Biophysical Profile Test.

Another application of the fetal audio stimulators **10** and **11** is to increase fetal heart rate. Fetal heart rate can be detected and monitored by a number of methods such as Doppler fetal heart rate monitor, a stethoscope, an ECG recording device, or ultrasound imaging.

The fetal audio stimulators **10** and **11** and associated motion detection devices **40**, **60**, and **80** can also be applied in fetal hearing tests. The fetal audio stimulators **10** and **11** of the present invention are particularly suited for fetal hearing testing, in that they provide the opportunity to test fetal hearing at each ear separately. The directed beam **27** produced by the ultrasound transducer **20** is effective on strong reflectors such as the middle ear bones, and can therefore be directed to the middle ears of a fetus bypassing the external ear and the eardrum. Fetal movements in reaction to the stimulation, as detected in any of the ways described above or through ultrasound imaging, or in other ways known to those of skill in the art, provides an indication of the hearing capabilities of the fetus. During these tests, the frequency selector **26** can be used to vary the audio level, thereby providing testing of the hearing range.

Fetal hearing of each individual ear of a fetus can also be tested at different audio frequencies by changing the frequency of the audio generator **14** using the frequency selector switch **26**, and then evaluating the lowest sound intensity to which the fetus responds. By this method it is

possible to produce an audiogram, for individual ears of the fetus, similar to the conventional audiograms that are obtained in audiology clinics for adult patients. An illustration of the results of a typical test is shown in FIG. 8, wherein hearing sensitivity in decibels is charted versus frequency in kilohertz. 5

Although preferred embodiments of the present invention have been shown and described, it will be apparent to those of ordinary skill in the art that the present invention can be implemented in various ways. For example the excitation signal for the ear stimulation transducer can be in the form of a pulse train instead of an amplitude modulated sine wave. In this case, the modulation unit can be deleted. The resulting sound would not be single tone in this case, and would have harmonics that are multiples of pulse repetition frequency. Furthermore, although various combinations of fetal audio stimulation devices and associated monitoring methods have been shown, it will be apparent that various features of each of these embodiments can be combined to provide variations of the embodiments shown. Furthermore, although specific applications have been described, it will be apparent that fetal audio stimulation devices can be applied in a number of applications in which it is desirable to stimulate a fetus or to cause a fetus to move or increase its heart rate. 10 15 20

It should be understood, therefore, that the methods and apparatuses described above are only exemplary and do not limit the scope of the invention, and that various modifications could be made by those skilled in the art that would fall under the scope of the invention. To appraise the public of the scope of this invention, the following claims are made. 25 30

What is claimed is:

1. A stimulation device for stimulating hearing in a middle ear of a fetus in utero, the stimulation device comprising:

- an RF generator generating a carrier signal;
- an audio generator generating an audio range signal;
- an amplitude modulator, electrically coupled to receive the carrier signal from the RF generator and the audio range signal from the audio generator, the amplitude modulator being operable to modulate the carrier signal with the audio range signal to produce a modulated stimulation signal; and

an ultrasound transducer electrically coupled to receive the modulated stimulation signal and being operable to convert the signal to a focused beam; 35 40 45

wherein the ultrasound transducer is adapted to be acoustically coupled to the fetus and positioned to direct the focused beam at an ear of the fetus to stimulate hearing and movement.

2. The apparatus as defined in claim 1 further comprising an amplifier electrically coupled between the amplitude modulator and the ultrasound stimulation transducer. 50

3. The apparatus as defined in claim 2, further comprising an amplitude control potentiometer electrically coupled in a feedback loop of the amplifier. 55

- 4.** The apparatus as defined in claim 1, further comprising:
- a gate electrically coupled to receive the modulated signal from the amplitude modulator and to provide the modulated signal to the ultrasound transducer; and
 - a gate control switch, the gate control switch being selectively activated to activate the gate, wherein the modulated signal is provided to the ultrasound stimulation transducer. 60

5. The apparatus as defined in claim 1, further comprising a frequency selector switch electrically coupled to the audio generator, the frequency selector switch being activated to select between a plurality of audio range signals. 65

6. The apparatus as defined in claim 1, further comprising: a demodulator circuit electrically coupled to receive the modulated signal from the amplitude modulator, the demodulator circuit producing a demodulated audio signal; and

an earphone, electrically coupled to receive the demodulated audio signal from the demodulator circuit, wherein the audio signal produced by the earphone can be monitored by a user to determine when the fetus is being stimulated.

7. The apparatus as defined in claim 1, further comprising: a strip chart recorder; and

a strip chart marker switch electrically coupled to the strip chart recorder, the strip chart marker switch being selectively activated to provide an indication to the strip chart recorder when a motion of the fetus is detected.

8. The apparatus as defined in claim 1 further comprising: a fetal monitor probe acoustically coupled to the fetus; and

a Doppler fetal monitor electrically coupled to receive a signal indicative of motion from the fetal monitor probe.

9. The apparatus as defined in claim 8, further comprising: a strip chart recorder; and

a chart marker, the chart marker being electrically coupled to receive a signal indicative of fetal motion from the Doppler fetal monitor and to provide a signal indicative of fetal motion to the strip chart recorder when a fetal motion event is detected.

10. The apparatus as defined in claim 1, further comprising:

- a receiving transducer;
- a mixer circuit, electrically coupled to receive the modulated signal from the amplitude modulator and to receive a reflected signal from the receiving transducer; wherein the mixer circuit down mixes the modulated and reflected signals to produce a down-mixed signal; and

a low pass filter electrically coupled to receive the down-mixed signal from the mixer circuit, the low pass filter filtering the down-mixed signal to produce a Doppler shift signal indicative of a movement of the fetus.

11. The apparatus as defined in claim 10, further comprising a monitor for monitoring the Doppler shift signal.

12. The apparatus as defined in claim 11, wherein the monitor is a video monitor.

13. The apparatus as defined in claim 11, wherein the monitor is an audio monitor.

14. The apparatus as defined in claim 1, further comprising:

- an arm having a first end and second end, the ultrasound transducer being pivotally coupled to the first end of the arm wherein the ultrasound transducer is adapted to be selectively directed at the head of the fetus;
- a receiving transducer, the receiving transducer being pivotally coupled to the second end of the arm, wherein the receiving transducer is adapted to be selectively directed at the heart of the fetus; and
- a Doppler fetal monitor electrically coupled to receive a signal indicative of a motion of the fetus from the receiving transducer.

15. A method for producing a localized sound in a maternal abdomen, the method comprising the following steps:

9

generating a carrier signal in an ultrasound range;
 modulating the carrier signal with an audio range signal to
 produce a modulated signal;

applying the modulated signal to an ultrasound stimula-
 tion transducer to produce a focused beam; and

acoustically coupling the ultrasound stimulation trans-
 ducer to the abdomen and directing the focused beam
 at a head of a fetus in utero, wherein a resultant force
 vibrates the middle ear of the fetus in the audio range.

16. The method as defined in claim 15, further comprising
 the step of applying the modulated signal to a demodulator
 to produce a demodulated audio signal.

17. The method as defined in claim 16, further comprising
 the steps of:

- monitoring the demodulated audio signal;
- monitoring motion of the fetus; and
- correlating the motion of the fetus with the demodulated
 audio signal.

18. The method as defined in claim 15, further comprising
 the step of detecting audio-induced motion of the fetus with
 a Doppler motion detector.

19. The method as defined in claim 15, further comprising
 the steps of:

10

focusing a receiving transducer for detecting signals in the
 same frequency range as the audio range signal at the
 same location as the ultrasound stimulation transducer;
 and

5 monitoring a reflected signal to detect a Doppler shift
 indicative of motion of the fetus.

20. The method as defined in claim 15, further comprising
 the steps of:

pivotaly mounting the ultrasound stimulating transducer
 to a first end of an arm;

pivotaly mounting a receiving transducer to the second
 end of the arm;

15 coupling the receiving transducer to a fetal monitor,
 monitoring a heart beat of the fetus with the fetal
 monitor, tracking fetal movement with the fetal moni-
 tor; and

correlating the motion to a location of the fetal ear.

21. The method as defined in claim 20, further comprising
 the step of determining the orientation angle of the stimu-
 20 lation transducer by evaluating a heart to ear distance, a
 focal length of the ultrasound transducer, a focal length of
 the receiving transducer, and a length of the arm.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,709,407 B2
DATED : March 23, 2004
INVENTOR(S) : Mostafa Fatermi

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1,
Lines 55 and 56, "a modulation" should be -- an audio --.

Signed and Sealed this

Thirteenth Day of July, 2004

A handwritten signature in black ink that reads "Jon W. Dudas". The signature is written in a cursive style with a large, looped initial "J".

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office